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Renewable energy production in the Zachodniopomorskie Voivodeship (Poland)

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ABSTRACT

The current state and the development prospects for renewable energy in the Zachodniopomorskie Voivodeship (Poland) have been presented. In this area there are 43 wind-power installations of total power of 726.429 MW, 69 hydropower plants of total power of 12.989 MW, over 250 biomass heat and heat and electric power plants of power exceeding 250 MW, one biomass and coal co-generation power plant. There is 22 million dm^3/year of bioethanol as well as 0.75 million dm^3/year of Rapeseed Methyl Esters (RME) produced. There are 10 biogas power plants located at municipal waste sites, 4 biogas power plants located at sewage treatment works and 4 agricultural biogas power plants. In the voivodeship there are geothermal power plants in Pyrzyce and Stargard Szczeciński. A few hundreds of solar thermal collectors and heat pumps have been installed. There are ten locations designated as a potential site for the construction of a nuclear power plant. In the near future it is planned that the renewable energy sector will continue to develop in the Zachodniopomorskie Voivodeship.

Contents

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1. Introduction

The reasons for attempting to use renewable energy sources include the limited amount of natural resources, increasing prices of fossil fuels and the environmental pollution [1,2].

In Poland energy is mostly obtained from hard and brown coal [3]. Joining the EU imposed a duty on Poland to adjust emission parameters to those binding in all EU countries. It spurred the development of the renewable energy sector. There are regions in Poland where renewable energy is developing very well. This is due to natural conditions, an interest among investors, the attitude of local authorities and local community as well as possibilities of obtaining funding for investment. The Zachodniopomorskie Voivodeship and Kujawsko–Pomorskie Voivodeship [4] lead the way in renewable energy production in Poland, with wind power generation being the best developed here. The percentage of renewable energy production in the Zachodniopomorskie Voivodeship is 20.8% (the voivodeship's area takes up 7.3% of Poland's area) whilst in the Kujawsko–Pomorskie Voivodeship it is 13.7% (the voivodeship's area takes up 5.7% of Poland's area) [5].

In this article we presented the results of sociometric research describing the current state and prospects of development of renewable energy in the Zachodniopomorskie Voivodeship. For this reason the research was carried out using surveys: "The Wind Power Sector in the Zachodniopomorskie Voivodeship" [6], "The Hydroenergy Sector in the Zachodniopomorskie Voivodeship" [7], "The Bioenergy Sector in the Zachodniopomorskie Voivodeship" [8], "The Helioenergy Sector in the Zachodniopomorskie Voivodeship" [9]. This is a continuation of the survey research from 2008 when the surveys were sent to the renewable energy producers in the Kujawsko–Pomorskie Voivodeship [4].

2. The description of the Zachodniopomorskie Voivodeship

The Zachodniopomorskie Voivodeship is located in the north-west of Poland, on the Baltic Sea Coast (Fig. 1). It covers the area of 22,892 km². The number of inhabitants is 1,722,883 and the voivodeship's authorities have their seat in Szczecin [10].

The climate of Zachodniopomorskie Voivodeship tends to be highly changeable, which is due to the oceanic and continental climate influences clashing within its area as well as local features (such as the land's topography and its elevation above the sea level) impacting on the weather phenomena. Through the centre of the voivodeship, from south-west to north-east, stretches a moraine rampart which significantly differentiates the spatial distribution of insolation, temperature, precipitation and wind speed on each side. The northern and western part of the voivodeship is characterised by small annual, seasonal and daily amplitudes of air temperature, high humidity and winds, a cooler summer and a short, mild winter as well as a significant amount of precipitation [11,12].



Fig. 1. The location of the Zachodniopomorskie Voivodeship in Poland (black colour).

In the area further away from the sea and more eastwards there are higher summer and lower winter temperatures, significant temperature amplitudes during a day, a longer winter with a long-lying snow cover. The vicinity of the Baltic Sea and Szczecin Bay leads to local differentiation of particular meteorological factors, the influence of which decreases during high-speed winds and movements of cyclonic systems. The mean annual air temperature in the voivodeship's area oscillates between 7.0 °C and 8.5 °C whilst the mean annual amount of precipitation oscillates from 490 to 770 mm. The prevailing wind directions are western and south-western [11,12].

The soils of the Zachodniopomorskie Voivodeship are characterised by high typological variation, different soil quality classes and agricultural capacity of soils. In terms of general soil capacity quality, the significantly dominant group consists of soils of medium value (soil classes IVa and IVb), which cover 50.8% of all the arable land. The second largest group consists of poor and very poor soils (soil classes V and VI). They cover 25.1% of arable land. Good soils (soil classes II, IIIa and IIIb) constitute the smallest portion and cover 24.1% of the arable land area [11,12].

The region has deposits of natural energy resources (natural gas, oil) as well as spastic iron ore, limestone, marl, lacustrine chalk, ceramic silt and clay, quartz sand as well as medicinal resources (therapeutic peat, thermal waters and brines) [11,12].

3. Wind power

The majority of Poland's area has good and fairly good wind conditions. The northern part of the Zachodniopomorskie Voivodeship (the seaside area) has highly favourable wind conditions. The Zachodniopomorskie Voivodeship currently leads the way in harnessing wind power to produce electric power in Poland. In the northern districts of the Zachodniopomorskie Voivodeship the wind turbines of the highest power are installed in Białogard district – 90 MW, in Kamień Pomorski district – 90.6 MW, in Kołobrzeg district 156.282 MW, in Koszalin district – 50.075 MW, in Sławno district – 200.258 MW. The wind turbines are located in 43 places (Fig. 2). The total power of all the wind turbines in the Zachodniopomorskie Voivodeship is 726.429 MW; all the power plants are located inland [5].

It is worth stressing that it was in the Zachodniopomorskie Voivodeship, in the locality of Cisowo (Fig. 2), where the first wind farm in Poland was created in 1999. The power plant consisted of 5 wind turbines of power of 132 kW each. The next farm followed in 2001; it consists of 9 wind turbines of power of 2 MW each, which gives a total of 18 MW for the whole farm [13].

The wind farm "Zagórze" started its operation in 2003. At the time of its start-up, the wind farm "Zagórze" was the largest farm in Poland and at that time the power installed there accounted for more than a half of the power of all the wind power plants in Poland. There are currently 15 wind turbines working there of power of 1 MW each. The budget of the investment reached about 125 million PLN. The mean wind speed in the vicinity of the Wind Farm "Zagórze", at the rotor's height, is 6.9 m/s. The annual electric power production is 56–72 GWh (this amount is equivalent to the electric energy consumption by 35,000 households) [14].

The Wind Park "Tymień" was opened in 2006. There are 25 wind turbines operating there, each of power of 2 MW. The wind

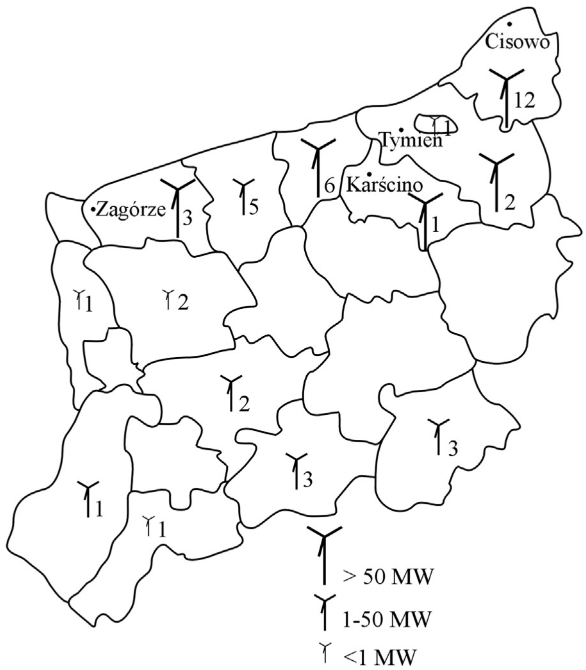


Fig. 2. The power of installed wind power plants and the number of wind turbines in the Zachodniopomorskie Voivodeship (own data based on [5]).

turbine construction is optimised to work in a wide range of wind conditions and to reduce emission of sound waves. The turbines are equipped in a microprocessor-controlled system, which regulates the blades' angle depending on the speed of incoming stream of air. It is estimated that the maximum power of wind turbines is reached at the wind speed of about 12 m/s [15].

The Wind Farm Karścino, currently the biggest one in the Zachodniopomorskie Voivodeship, was built between 2007 and 2009. The power plant comprises 60 wind turbines in the area of about 500 ha, the total nominal power of the farm is 90 MW [16].

3.1. Prospects

It is currently noticed that companies are showing a great interest in wind projects in the Zachodniopomorskie Voivodeship. This interest is related to good wind conditions as well as the significant development of renewable energy sector in Poland. The construction of off-shore wind farms is often being considered in addition to inland wind power stations [17].

The planned start-up of a wind farm in the vicinity of Darłowo, of total power of 240 MW, will increase the renewable energy production in Poland by 11% compared to the level in 2009. Thus, the target of generating 15% of energy from renewable energy sources in Poland could be achieved earlier than 2020 [17].

According to the data of Institute for Renewable Energy [18], the economic potential of the wind power sector in the Zachodniopomorskie Voivodeship is 16 GW and is the highest in Poland. Due to the current market and political conditions between 2014 and 2020 the highest number of wind turbines will be located in the Zachodniopomorskie Voivodeship.

According to “The Programme for the Development of Energy Sector in the Zachodniopomorskie Voivodeship until 2015 with the Forecast till 2030” [19], there are three scenarios that could be considered by 2015:

I. 600 MW of power installed on wind farms is achieved, which necessitates the construction of new wind turbines of total power of 200 MW,
II. 800 MW of power installed on wind farms is achieved, which necessitates the construction of new wind turbines of total power of 400 MW, and
III. 1000 MW of power installed on wind farms is achieved, which necessitates the construction of new wind turbines of total power of 600 MW.

Scenario II seems to be the most realistic, which means that the power of wind turbines would be doubled.

The construction of further wind farms encounters barriers due to limited transmission capacity of power grids of various voltage (transmission capacity is a limiting factor when it comes to securing a permit on connecting newly constructed sources to the grid) as well as ecological reasons (protected sites). Other factors hindering the development of wind power sector include time-consuming town and country planning procedures as well as an assessment of environmental impact of wind turbines [20]. The waiting time to obtain a permit to construct a wind turbine in the Zachodniopomorskie Voivodeship is as long as 49 months [21].

The emerging wind farms face increasingly frequent opposition from the local community. The wind farm opponents most often cite the arguments of damage to the landscape and tourist attractions of a given locality as well as the negative impact of wind turbines on birds' migration. People who will live near the wind farms are afraid of noise produced by power plants and changes in the electric-magnetic field. Educating the local community brings positive results. The construction of the Tymień power plant did not meet any opposition. On the contrary, the residents and local authorities hope that wind turbines will become a tourist attraction, which will entice tourists relaxing at the seaside. The construction of the wind power plant within the municipality will generate financial income (real estate tax) and new work places [21]. According to the estimates of the Polish Wind Energy Association [22] there are 700 people employed by the wind power sector in the Zachodniopomorskie Voivodeship and at the end of 2010 there were employed about 2500 people in the whole of Poland (FTE). In 2020 the number of work places in the wind power sector could rise to 66,000.

3.2. Surveys

Respondents to the survey “The Wind Power Sector in the Zachodniopomorskie Voivodeship” [6] were individual investors. Wind turbines were constructed between 2009 and 2012. The investors the most often indicated that they had two wind turbines (42% of respondents) or one wind turbine (34% of respondents). As for the other respondents, 8% had 4 wind turbines and the remaining 16% of survey participants did not provide the number of wind turbines.

The duration of wind investment implementation was most often contained within 12–24 months (50% of respondents). It was only one person that indicated that implementation took less than one year whilst for other investors it was more than two years. Investment costs as per one wind turbine were:

- up to 200,000 PLN: 8% of respondents,
- 200,000–500,000 PLN: 24% of respondents,
- 500,000–1000,000 PLN: 34% of respondents, and
- Above 1000,000 PLN: 34% of respondents.

The respondents estimated the playback time for an investment to be 8–15 yr. Most often it was 10 yr (56% of respondents). The power of wind turbines varied between 0.05 and 2 MW. The majority of respondents were planning to construct new wind turbines in future. They also stressed that this was still a relatively expensive investment with a long playback time. They drew

attention to increasingly greater investment problems: a long waiting time for a permit, opposition from environmental groups as well as difficulties to get connected to the power grid.

4. Hydropower

The total length of water courses within the boundaries of the Zachodniopomorskie Voivodeship is 30,200 km. The mean density of river network in the voivodeship is 1.32 km/km^2 [23].

In the Zachodniopomorskie Voivodeship there are currently 69 hydropower plants of total power of 12.989 MW (Fig. 3). The vast majority of power plants are very small, of power between 11 and 19 kW. The power plant of the highest power (3.3 MW) is located in the locality of Rosnowo [5,24].

The hydropower plant Rosnowo, which is the largest in the Zachodniopomorskie Voivodeship, opened at the site of a former water mill in 1922. The power plant uses water retained in the Rosnowskie Lake and co-operates with the constructed in 1912 hydropower plant Niedalino. The water is supplied from the Rosnowskie Lake to the power plant by an inlet canal of 2.7 km. The difference between water levels of 16.4 m is used. Three horizontal-shaft twin Francis turbines of power of 1.1 MW each are installed in the power plant [25].

In the Zachodniopomorskie Voivodeship there is also a pumped storage power plant in Żydowo (Fig. 3). The two natural lakes: Kamienne and Kwiecko, located near each other and of a significant difference (80 m) of water tables, are connected by three steel pipelines, 5 m in diameter. Every second there is 240 m^3 of water directed at the turbine's blades, due to which the power plant can generate power of 156 MW. During night-time energy surplus in the network two reversible turbine generator sets pump back 3 million m^3 of water to the higher reservoir [26].

4.1. Prospects

Due to a limited energy potential of rivers as well as environmental conditions, hydropower's development prospects are constrained. It is possible to construct small hydropower plants on rivers directly flowing to the Baltic Sea [23].

There are over 240 hydrotechnical structures on the rivers of the Zachodniopomorskie Voivodeship, including 183 weirs altering water in the river beds, 39 hydrotechnical structures located where rivers flow out from lakes as well as 13 reservoirs [23]. The hydrotechnical structures are only partly used to generate energy (currently there are 69 operating power plants). According to "The Small Retention Programme" [27] these hydrotechnical structures are where small hydropower plants will be built. The construction of new hydrotechnical structures is recommended due to the geographical location of the Zachodniopomorskie Voivodeship. As a result of oceanic climate various types of floods may occur, caused by rainfall, meltwater, ice-jam and storms. On the other hand, there are years with long-term draughts with negative impact on forests and agriculture [27].

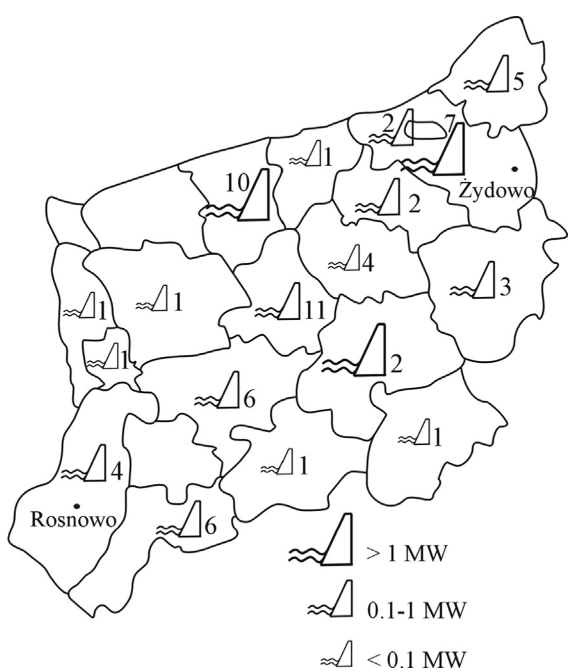


Fig. 3. The power and number of hydropower plants in the Zachodniopomorskie Voivodeship (own data based on [5]).

4.2. Surveys

The survey "The Hydroenergy Sector in the Zachodniopomorskie Voivodeship" [7] was answered by individuals owning hydropower plants located on the rivers (90%) or on other water courses (10%). The power plants were constructed between 1967 and 2005. The time of investment implementation took between 1 and 36 months, but the most often it was 24 months. The investment costs were:

- up to 200,000 PLN: 48% of respondents,
- 200,000–500,000 PLN: 36% of respondents, and
- 500,000–1000,000 PLN: 16% of respondents.

Generated energy was partly used to meet own needs (up to 5% of generated energy) and the rest was sold. The respondents estimated the investment playback time to be between 10 and 18 yr. Only one responded was planning to construct a new hydropower plant.

Similarly to wind turbines, respondents stressed that it was still a relatively expensive investment with a long playback time. They drew attention to increasing problems with investments: a long waiting time for permits as well as difficulties getting connected to the power grid.

5. Biomass

The biomass market in both Poland and the Zachodniopomorskie Voivodeship is still in its development stage [19,28]. The significance of biomass on the fuels' market is increasing every year. It is estimated that currently in the Zachodniopomorskie Voivodeship there are over 320 boiler plants of total power exceeding 250 MW, in which mostly forest biomass is burnt. The amount of obtained waste timber (soft timber, hard timber, small timber) is gradually increasing, reaching over 500,000 m^3 per year. In the Zachodniopomorskie Voivodeship there are a few boiler plants that use straw as a fuel [19].

Industrial waste wood is more frequently used to generate heat. This type of waste material is often burnt where it is produced or it is turned into pellets and briquettes. In the Zachodniopomorskie Voivodeship the greatest amount of timber industry waste is produced by "Barlinek Inwestycje" company ltd. (around 200 Gg per year) as well as "Koszalin Timber Industry Company" (around 110 Gg per year). On the other hand, straw is mainly burnt in small local boilers to meet heating demand [19].

Biomass, in the form of sawdust, is transported by means of motor transport to the power plant "Dolna Odra" in the locality of Nowe Czarnowo (Fig. 4) where it is co-fired with coal. Initially,

biomass was mixed with coal in the coal yard using bulldozers. However, this practice was soon abandoned as it was highly labour-consuming and it was impossible to precisely measure the weight ratio of coal to biomass. Currently, biomass is stacked into mounds and transported by a conveyor belt. The conducted research has concluded that up to 15% weight of sawdust can be co-fired. This addition of biomass makes it possible to achieve 7.4% of total electric power production. Adding wood to coal results in lowering SO_2 and CO emission by a few per cent [29].

The Szczecin power plant has the largest fluidised boiler with a bubbling fluidised bed (BFB) in Poland, which is fuelled by biomass. The boiler started its operation in January 2012. It is possible to generate in it 440 GWh of electric power and 1900 TJ of heat per annum. In the boiler there is 550 Gg of biomass combusted per year. As a result of replacing coal with biomass, the emission of sulphur dioxide decreased by 69% and the emission of dusts fell by 63% [30].

Biofuels are also produced in the Zachodniopomorskie Voivodeship. In the locality of Ińsko 22 million dm^3 of bioethanol is produced per year whilst in Ciesław 0.75 million dm^3 of RME is produced per year (Fig. 4.) It is worth mentioning that at the bioethanol plant in Ińsko a modern membrane technology of pervaporation was implemented during the dehydration stage [31,32].

In the Zachodniopomorskie Voivodeship biogas is also produced for energy purposes. The most of biogas plants (10) use biogas generated at municipal waste dump sites [5]. The amount of municipal waste produced in households and public buildings in the Zachodniopomorskie Voivodeship reaches about 572 Gg, of which more than half consists of biodegradable waste [33–35].

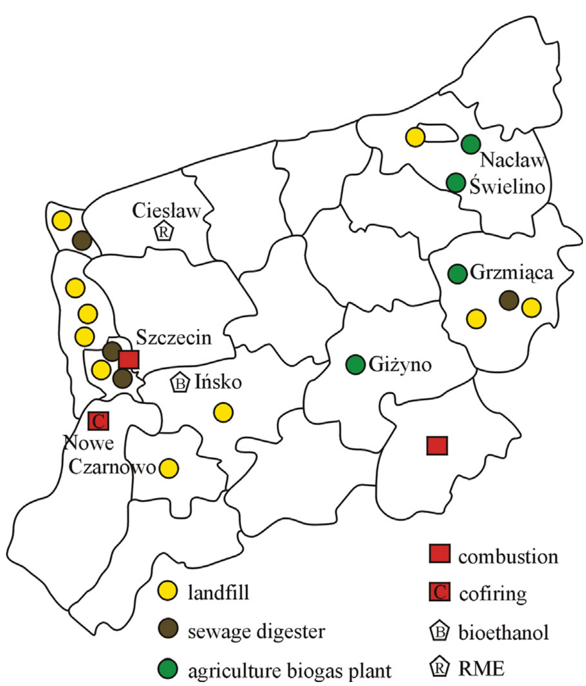


Fig. 4. Bioenergy production in the Zachodniopomorskie Voivodeship (own data based on [5]).

In the Zachodniopomorskie Voivodeship there currently operate over 290 municipal sewage treatment plants of total flow capacity of 440,000 m^3 per 24 h. Obtained as by-product, sewage sludge can be utilised for agricultural purposes, burnt or can undergo anaerobic fermentation. In the Zachodniopomorskie Voivodeship there are currently four operating biogas plants located at the sewage treatment works. Electric power and heat obtained from generated biogas are used on site, increasing the plants' profitability, or are sold [36].

The following substrates can undergo a methane fermentation: farm livestock's droppings, slaughterhouse waste, crop cultivation waste, purposefully grown energy crops, food waste, a waste product of biodiesel – glycerol etc. Currently there are four agricultural biogas plants operating in the Zachodniopomorskie Voivodeship (Fig. 4). The main substrates of these biogas plants include slurry and maize silage (Table 1) [37–41].

5.1. Prospects

Forestation rate of the Zachodniopomorskie Voivodeship is 35.2% and is higher than the average for Poland, which is 29.2% [11]. Assuming that 15% of timber obtained directly in the forest could be used for energy purposes (parts of bark, slash, more chunky waste wood created during logging), then 562,000 m^3 of waste wood could be obtained per year.

A significant amount of wood waste in the Zachodniopomorskie Voivodeship is created by the timber industry – sawmills, furniture industry companies, pulp and paper industry companies (sawdust, wood shavings etc.). Another source of wood is used timber. It can be assumed that the amount of waste forest biomass obtained from industry and used timber is at least the same as the amount of waste wood obtained in the forest [42].

The area taken up by orchards in the Zachodniopomorskie Voivodeship is 34,700 ha [11]. The timber from orchards is obtained through both felling and maintenance work (trimming of branches). As a result of felling of orchards it is technically possible to obtain about 80 Mg of biomass per 1 ha in case of older plantations (about 30 yr old) and about 60 Mg/ha in case of modern dwarf plantations (about 15 yr old). The amount of biomass created during maintenance work varies, depending on the age and variety of trees, from 4 to 10 Mg/ha [43]. Assuming that due to felling of orchards 3.5 Mg of biomass can be obtained per 1 ha per year and that as a result of maintenance work 7 Mg of biomass is created per 1 ha per year, then it is possible to obtain 259,000 Mg of waste biomass from orchards in the Zachodniopomorskie Voivodeship.

In 2011 the Zachodniopomorskie Voivodeship produced about 727 Gg of wheat straw, 327 Gg of rye straw, 232 Gg of barley straw, 140 Gg of oats straw and 191 Gg of triticale straw [11]. Around 35% of straw could be used to generate energy. Currently, this potential is realised only to a small degree.

According to the Institute for Renewable Energy [18] the economic potential of bioenergy in the Zachodniopomorskie

Table 1
Technical characteristics of agricultural biogas plants in the Zachodniopomorskie Voivodeship as of December 2012 (own data based on [37–41]).

Locality	Substrates	Efficiency (million m^3 of biogas/year)	Power (MW)		Annual production (GWh/year)	
			Electric	Thermal	Electric power	Thermal power
Giżyno	Slurry, maize silage	4.100	1.063	1.091	8.380	8.520
Grzmiąca	Plant and animal production waste	7.000	1.600	1.600	13.500	13.500
Nacław	Slurry, maize silage, glycerol, plant production waste	2.995	0.625	0.686	4.927	5.408
Świetlino	Slurry, maize silage, glycerol, plant production waste	2.299	0.625	0.686	4.927	5.408

Voivodeship is 454,000 Mg of biomass from energy crops plantations.

Currently, every Polish biogas plant uses animal droppings as a main substrate. The technical potential of biogas in the Zachodniopomorskie Voivodeship was calculated taking into consideration conversion factors of livestock heads into Livestock Units *LSU* (500 kg) [44] – for cattle the conversion rate is 0.8, for pigs – 0.2, for poultry – 0.004. The mean amount of slurry per 1 LSU is 44.9 kg for cattle, 43.5 kg for pigs and 26.8 kg for poultry [45]. The number of heads was taken from the data of the Central Statistical Office [46]. It is assumed that biogas contains 58% of methane. The construction of biogas plants using slurry and/or poultry manure is technically and economically viable on farms with the livestock number of at least 100 heads of cattle, 500 heads of pigs and 5000 heads of poultry [47]. Thus, the technical potential of agricultural biogas from animal droppings in Poland in 2011 should be estimated at 25% of theoretical potential. The production of biogas from 1 Mg of cattle slurry is estimated to be 50 m^3, from pig slurry – 55 m^3 and from poultry manure – 140 m^3. The amount of biogas which could be obtained in the Zachodniopomorskie Voivodeship is 47 million m^3.

The amount of municipal waste created in households and public use buildings in the Zachodniopomorskie Voivodeship is 0.572 million Mg, of which more than a half consists of biodegradable waste [44]. Due to a high distribution of bio-waste sources as well as a low degree of their segregation, the technical potential of biogas from municipal waste can be estimated at the level of 15% of theoretical potential. Assuming that it is possible to obtain 90 m^3 of biogas from 1 Mg of biodegradable waste, then 3.9 million m^3 of biogas can be obtained from municipal waste in the Zachodniopomorskie Voivodeship.

In the Zachodniopomorskie Voivodeship 13.6 million m^3 of municipal sewage is treated [46]. Assuming that from 50% of influents flowing into the sewage treatment works sludge is obtained (which is equivalent to 1% of influents) and that 15 m^3 of biogas can be obtained from 1 m^3 of sludge, then 1.0 million m^3 of biogas could be obtained in the Zachodniopomorskie Voivodeship.

5.2. Surveys

The answers to the survey “The Bioenergy Sector in the Zachodniopomorskie Voivodeship” [8] were provided by respondents who own installations for biomass combustion and a few biogas plants. They used a wide variety of energy resources mainly for heating purposes: sawdust, chips, straw, ground grain, waste wood from forest logging and sawmills, shavings from wood processing and furniture companies, pellets and briquettes from waste wood, straw and energy crops. It should be noted that certain boiler plants burn a few different types of biomass. The amount of combusted biomass varied significantly: from a few Mg to over a million Mg per year. The investment costs reached between 10,000 PLN (individual boilers) and about 2 million PLN (large heat-generating plants).

Almost all respondents (90%) mentioned overtly high investment costs as the greatest obstacle to project implementation, whilst some pointed to excessive bureaucracy. The respondents estimated the waiting time for investment return to be 10–15 yr. The following were considered to be the most important operating problems:

- excessive dampness of biomass,
- not enough of biomass suppliers,
- high prices of “commercial” biomass, and
- no market availability of certain spare parts for technical equipment.

Biogas plants used municipal waste or sludge to generate biogas. The construction of biogas plants took from 8 months to 2 yr whilst the investment costs in most cases exceeded 7 million PLN.

The most important issue for respondents during investment implementation was high cost. Also, in some cases there were problems getting connected to the power grid. The majority of biogas plants sold produced energy mainly to the state energy company and in a few cases to private firms. Energy used to meet own needs was mainly utilised by biogas plants operating at the sewage works.

6. Solar power

Solar power is becoming more widely used in the Zachodniopomorskie Voivodeship. This growth is linked to greater availability of technologies, funding programmes for installing this type of solutions, increasing environmental awareness and rising prices of energy from conventional sources. On the market there are available new solutions combining the traditional energy sources (e.g. LPG) with solar power, which leads to greater independence from negative atmospheric conditions (e.g. during winter) [18,23].

Annual solar radiation density on a horizontal plane in Poland varies between 950 and 1250 kWh/m^2. The northern part of the Zachodniopomorskie Voivodeship has some of the highest solar radiation values (above 1200 kWh/m^2) (Fig. 5). Around 80% of the total annual solar radiation takes place during six months of the spring–summer season, from the beginning of April till the end of September; the duration of solar operation increases to 16 h per day in summer whilst in winter it falls to 8 h per day [48,49].

There are two types of solar thermal collectors that have been sold over the last few years in the Zachodniopomorskie Voivodeship: mainly liquid flat plate collectors (70%) and, to a smaller extent, evacuated solar tube collectors (30%). The greatest number of solar collectors is installed in large cities (Fig. 5). Collectors are installed in public offices as well as detached houses [19].

For example, on the premises of one of the companies in Szczecinek 8 solar thermal collectors PE200S were installed that work together with a heat pump Ochsner. The collectors are located on the building's roof. The system of collectors is located on the southern side (with a deviation of 5% towards the west). This system provides heat to a building of 500 m^2 area. The solar system ensures 80% of hot usable water and up to 30% of central heating [49].

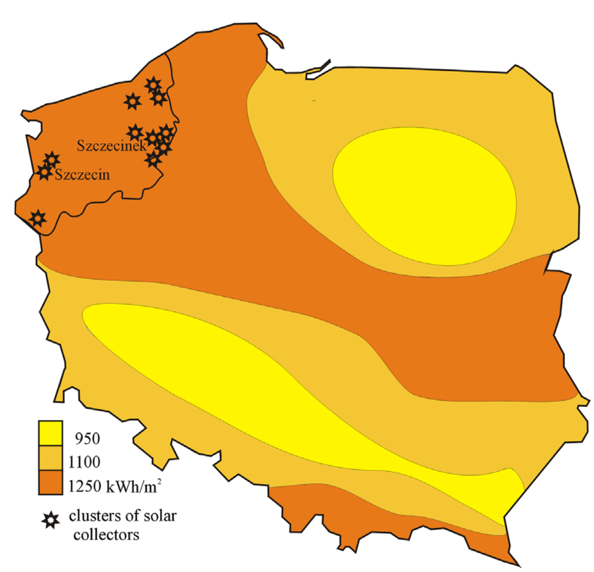


Fig. 5. Solar radiation density in the Zachodniopomorskie Voivodeship in comparison to the whole of Poland (own data based on [48,49]).

On the other hand, on the roof of a block of flats of TBS Housing Association in Szczecinek three systems of Vitosol solar thermal collectors were installed (each containing 12 collectors). Each system works together with two water heaters which are containers of capacity of 750 dm^3 each. As a result, warm water, heated up to a temperature of 55–60 °C is transported to households. This system provides warm water for 220 people. The heating power of the whole system is 43.56 kW [49].

6.1. Prospects

The tendency to harness solar power to produce hot usable water in individual households as well as the public sector (swimming pools, schools etc.) will continue in the near future. Photovoltaic cells will be utilised to a much lesser scale, just to power traffic lights, road signs or parking metres. Small solar power plants could be built too. For example, there is a plan for a solar power plant of power up to 30 MW to be constructed in Chojna [50].

According to the Institute of Renewable Energy [18] the market potential of solar power sector in the Zachodniopomorskie Voivodeship till 2020 is 800 TJ, which is due to installing 0.6 million m^2 of solar collectors.

6.2. Surveys

The answers to the survey “The Helioenergy Sector in the Zachodniopomorskie Voivodeship” [9] were provided by individual investors as well as public offices (schools, swimming pools etc.). Flat plate collectors were installed most often. The respondents had the collectors of renowned companies fitted in the following years:

- 1999–2002: 5%,
- 2003–2006: 25%,
- 2006–2009: 35%, and
- 2010–2012: 35% of survey participants.

The implementation of the solar investment the most often took from one day to one month (55% of survey participants) or up to two months (35% of survey participants). The investment cost depended mainly on the number and size of collectors as well as the modernisation of the heating system that was carried out; there was a wide range of variation:

- up to 10,000 PLN: 10%,
- 10,000–15,000 PLN: 45%,
- 15,000–20,000 PLN: 35%, and
- above 20,000 PLN: 10% of survey participants.

The waiting time for the investment return was described by the respondents as 4–16 yr, with 10 yr being mentioned the most often (40%).

Only 30% of survey participants provided the information about the power of their collector (collectors) – it varied between 1 kW and 0.8 MW. Almost all the respondents were satisfied with the solar collectors' performance. During the spring–summer season the energy savings reached from 30% to 90% whilst during the autumn–winter period, from 10% to 40%.

The installation of further solar collectors is planned in future by 20% of the survey participants. The respondents emphasised that the solar installations operation was practically trouble-free and there was a little need for a maintenance work. However, they also stressed that it was still a relatively expensive investment with a long playback time.

7. Geothermal energy

The terrestrial heat stream density in Poland shows great differentiation, depending on the geological composition, and varies from 50 mW/m^2 to 100 mW/m^2. In the Zachodniopomorskie Voivodeship the heat stream density reaches from 60 mW/m^2 to nearly 100 mW/m^2 (Fig. 6) [51]. In the Zachodniopomorskie Voivodeship the temperature of underground waters in the Lower Jurassic rocks reaches from 20 to 95 °C. The resources of geothermal energy in the Zachodniopomorskie Voivodeship can be described as significant enough to provide heating for houses and public buildings, drying rooms, greenhouses, to heat up hot usable water and to be used for balneological and recreation purposes [52,53].

Currently, there are two geothermal boiler plants in the Zachodniopomorskie Voivodeship: in Pyrzyce and Stargard Szczeciński (Figs. 6 and 7) [51,53].

In September 1992 the plant design work was commenced in Pyrzyce and the drilling of three geothermal bore-holes took place. This was followed in the middle of 1993 by the implementation of the geothermal system, volume objects and a heating system network directed towards the town [54,55]. The depth of the geothermal wells is approximately 1620 m, whilst the mean water temperature in the bed is about 64 °C. The static level of the well water table becomes stabilised at a depth of 34 m below the ground. Consequently, geothermal water is exploited by means of multi-gradient deep-well pumps installed at a depth of 110 m. The exploited geothermal water of 61 °C temperature, after passing through filters, is directed to a first-heat exchanger, where the heat is transferred to the returning water network. In the heat exchanger the network water is heated up to, depending on conditions, 40–60 °C. In order to optimise the use of heat energy from geothermal water, the water is directed to a exchanger, where it is cooled down to a temperature of 26 °C. This is possible because a part of the returning network water was previously cooled down in an absorption heat pump evaporator. After leaving the second-heat exchanger, the geothermal water is then transported through the set of filters and is pumped back to the very same geological layer from which it was exploited. The pumping wells are located about 1.5 km from the production wells [53–55].

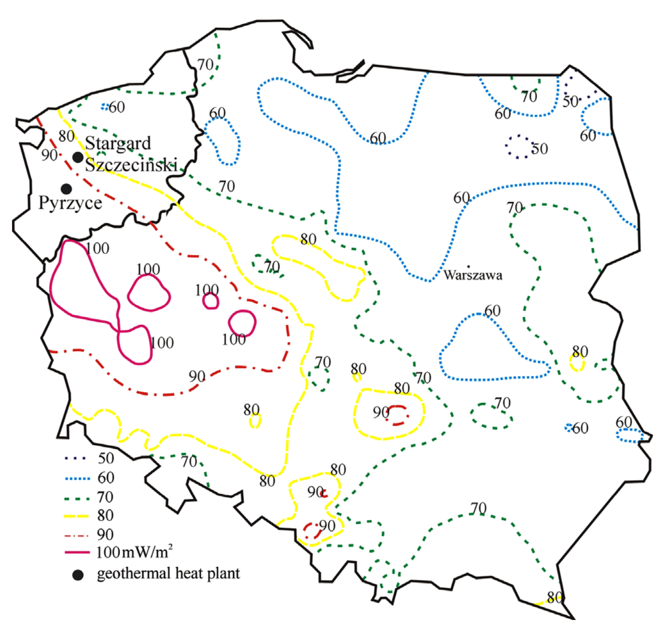


Fig. 6. The map of the terrestrial heat stream density for the Zachodniopomorskie Voivodeship in comparison to the whole of Poland (own data based on [51]).



Fig. 7. The hall of a geothermal heat plant in Pyrzyce (photography B. Igliński).

The construction of a geothermal heat plant in Stargard Szczeciński was completed in 2005. During an initial stage of investment the first (vertical) 2760 m deep exploitation well was drilled. The geothermal water is characterised by high salinity: 120 g/cm^3. In 2006 the heat plant produced 148 TJ of heat. It had been expected that a flow of geothermal water of 250 m^3/h at a temperature of 89 °C would provide 14 MW of heat power [56]. Since the commencement of its operation, the heat plant has serious technical problems: pumping of the brine into the rock formation being the largest problem. This significantly reduces heat power as well as the amount of heat transported to the municipal heating system. The main cause of a decline in pumping efficiency is too high salinity of water and resulting from it salt precipitation. Research is being currently undertaken in order to solve this problem [56,57].

7.1. Prospects

The highest geothermal energy potential in the Zachodniopomorskie Voivodeship is in its south-western part; it is possible to achieve their power at a level of 2.5–3 MW. The construction of new geothermal heat plants is viable in towns where prospective heat recipients are located [19,53].

In the near future the market for heat pumps will continue to develop further. The observation of the heat pump market leads to a conclusion that they tend to be installed in newly constructed or renovated buildings. It is estimated that the number of various types of heat pumps installed in the voivodeship reaches a few hundred items per year. In the near future this number could rise even by 1000 items per year (power of about 10 MW) [53].

8. Nuclear power

The Polish Nuclear Power Programme [58] stipulates in the first stage the construction of 2–3 nuclear power plants of total power of about 6 GW. The decision about the location of the first and possibly of the next few nuclear power plants is to be made by the end of 2013. The Zachodniopomorskie Voivodeship clearly leads the way in terms of the number of proposed sites for nuclear power plants; 10 out of 28 proposed sites in Poland are located in this voivodeship (Fig. 8). Apart from the availability of cooling water, other factors that could determine the final decision about the location of a nuclear power plant in the Zachodniopomorskie Voivodeship include: the power grid infrastructure ensuring the receipt of energy, a well-developed transport infrastructure (easily accessible sea, land and air transport), a suitable construction site, accepting attitude of the local community [58,59].

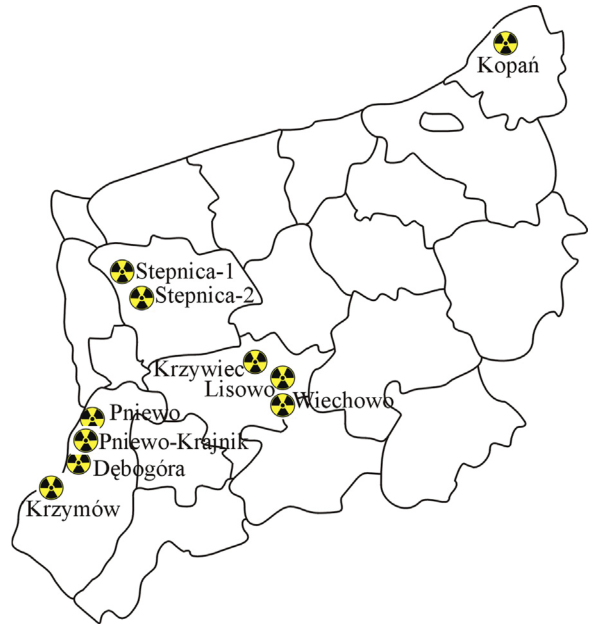


Fig. 8. Proposed sites for the construction of a nuclear power plant in the Zachodniopomorskie Voivodeship (own data based on [58,59]).

Among ten proposed locations in the Zachodniopomorskie Voivodeship the seaside site “Kopań” seems to be the best one. The easy availability of large quantities of cooling water (the sea is 1 km away) enables a 2–3% saving on the exploitation costs. The availability of cooling water (the Szczecin Bay) is a feature shared by “Stepnica-1” and “Stepnica-2” sites. “Krzywiec” and “Krzymów” are other locations considered due to a well-developed power and industry infrastructure and, as shown by initial surveys, due to a high support from the local community. A disadvantage of “Krzywiec” and “Krzymów” sites is a need to use much more expensive cooling system of cooling towers [58,59].

9. Conclusions

Every type of renewable energy is being developed in the Zachodniopomorskie Voivodeship, but the strongest tendency for development lies with wind power. The wind turbines of the highest power in Poland (about 2 MW) are erected in the Zachodniopomorskie Voivodeship. The largest wind farms (Zagórze, Tymień, Karościno) are also located in this region. On the other hand, hydropower plants are of reduced power – these are small structures, exerting virtually no negative impact on the environment. In the voivodeship the solid biomass is mainly used for heating purposes (over 250 heat plants and heat and power plants). The development of biogas plants is noticeable; an interest in agricultural biogas plants is constantly increasing. The Zachodniopomorskie Voivodeship has the best solar conditions in Poland. A trend to harness solar power to provide usable hot water in individual households and the public sector (swimming pools, schools) will continue in the near future. It is estimated that the number of heat pumps installed in the voivodeship could increase even by 1000 items a year.

According to “The Programme for the Development of the Zachodniopomorskie Voivodeship's Energy Systems in Terms of Improving Energy Security and Ensuring the Continuity of Supplies” [59] one of the strategic goals is “The Development of

Renewable Energy Sources and New Environmentally Friendly Energy Generating Technologies." This target is to be achieved by:

- modernisation and extension of the power grid infrastructure so as to enable the connexion of new renewable energy sources as well as the transfer of electric power surplus to other regions of the country,
- a significant development of the renewable energy sector, also including a significant development of the energy sector inland and eventually off-shore,
- reduction of the energy sector's environmental impact, and
- rational exploitation of biomass resources.

The installations using the renewable energy sources in the Zachodniopomorskie Voivodeship are locally distributed and do not require establishing a centralised technical infrastructure. The construction of further renewable energy structures in the voivideship's region will contribute to improving the condition of the natural environment as well as creating new work places [59,60].

According to the sociometric surveys, investing in renewable energy sector is still relatively expensive with a long waiting time for a financial return. Survey respondents also draw attention to a long waiting time for permits, opposition from environmental groups and difficulties getting connected to the power grid. Despite numerous obstacles the respondents still want to invest in the renewable energy sector (mainly wind power) in the Zachodniopomorskie Voivodeship.

Poland has a great potential for renewable energy production, but formal and legal barriers as well as technical and information barriers are still hampering its development [2,61]. The most important problematic areas include: lack of stability of legal regulations on renewable energy sector; difficulties meeting conditions for getting connected to the electric power grid; unclear fiscal and tax regulations; a poor power infrastructure; a difficult access to procedures and costs of investment process [62,63].

Another factor that significantly hinders the renewable energy sources [RES] development is the lack of local spatial development plans as the preparation of and gaining approval for such a plan is one of the longest parts of the project development cycle and takes about two years. It is worth mentioning information and educational barriers, which lead to underestimation of roles and possibilities of the renewable energy sector in terms of power generation [62,63].

The state of the renewable energy sector in Poland should be improved by "The act on renewable energy sources", the draft of which should be sent to Sejm [the lower house of the Polish parliament] at the end of 2013 or at the beginning of 2014. The act is supposed to improve the support systems for the renewable energy sector in Poland; favourable conditions for the development of off-shore wind power are also to be created.

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